Properties of Vapor-Deposited Au:Er Films for Metallic Magnetic Calorimeters

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Constellation- X Mission

High energy resolution x-ray spectroscopy with a micro-calorimeter will start a new era for x-ray astronomy.

Science goals are to study:
- Effects of strong gravity in the vicinity of black holes
- Origin and evolution of supermassive black holes
- Dark Energy and dark matter
- Life cycles of matter

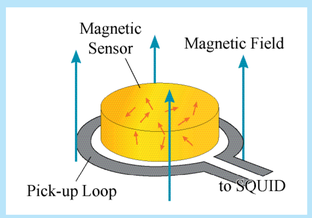
To achieve these goals, requirements for an x-ray detector are:
- $\Delta E_{FWHM} < 4$ eV resolution at 6 keV
- Large focal-plane arrays of detectors (32 x 32 pixels)

Metallic Magnetic Calorimeters (MMCs)

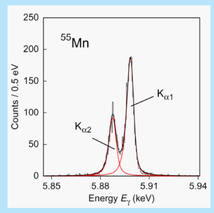
Detection Principle

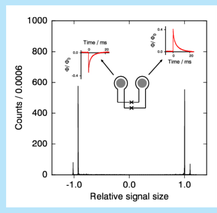
- Paramagnetic sensor diluted in a non-magnetic metal: Au:Er
- Change in magnetization due to temperature rise in sensor is detected by a SQUID.

$$\delta\Phi \propto \frac{V}{r}\frac{\partial M}{\partial T}\frac{\delta E}{C_{total}}$$



Energy resolution $\Delta E_{FWHM} = 3.4$ eV





Two-pixel detector; Au:Er sensors and Au absorbers are manually assembled on SQUID chip

(Fleischmann et al., Nucl. Instr. and Meth. A 520 (2004) 27)

Fabrication of Au:Er Film

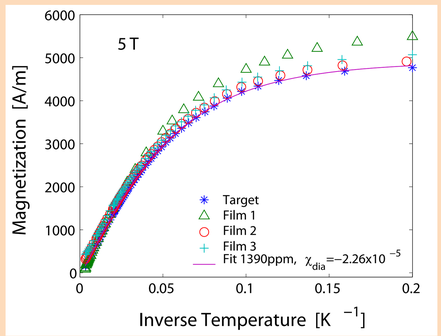
Au:Er film was deposited onto photoresist-coated Si substrate by DC magnetron sputtering. The gold target was doped with 1400 ppm natural Er, prepared by the Ames Laboratory. The substrate was maintained at room temperature during deposition. The chamber was pumped down to ~10^{-7} torr before deposition. The films were lifted off the substrate after deposition. Three Au:Er films were deposited under different sputtering conditions:

	Cathode Power	Deposition Rate [Å/sec]	Thickness [μm]	RRR
Film 1	Low	7.4	4.5	1.70
Film 2	High	14.8	4.5	1.75
Film 3	High	36.7	5.5	1.71

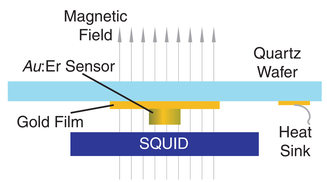
Magnetization of Sputtered Au:Er Film

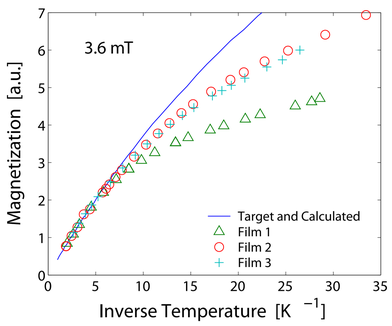
High Temperatures

- SQUID magnetometer was used to measure magnetic moments of the target material and the sputtered films.
- Target has 1390 ppm Er concentration determined from the fit.
- Film 1 has 20% higher Er concentration than the target.
- Film 2 and 3 have the same Er concentration as the target.



Low Temperatures

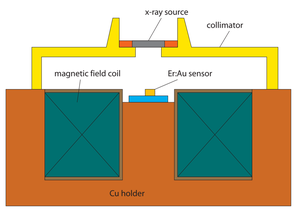


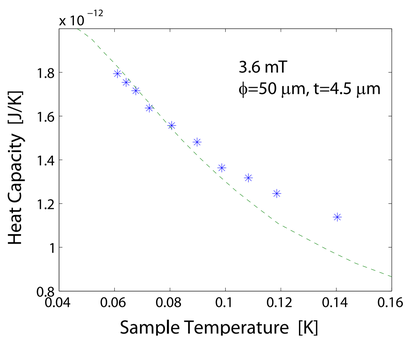


Below 200 mK the magnetization of the target material agreed with the mean field calculation of the magnetization for 1400 ppm natural Er, but that of the sputtered films deviated in such a way that the change in magnetization with respect to temperature is less than predicted. The implication of this is that there is a larger exchange interaction in the films than exists between the randomly distributed Er ions in the bulk material, as assumed in the mean field calculation.

Heat Capacity Measurement

The heat capacity of film 2, which showed the least deviation in magnetization at low temperatures, was measured.





The measured heat capacity agrees to within 10% with calculation. The calculation includes contributions from Zeeman, exchange, and hyperfine interactions from 23% abundant ^{167}Er isotope.

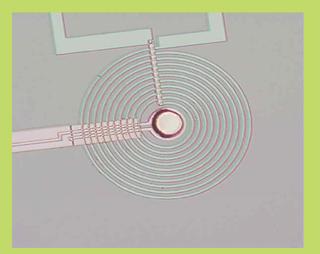
Discussion and Conclusion

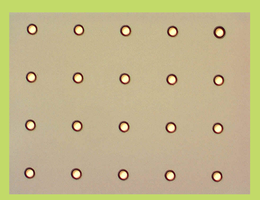
The high-temperature magnetization of the sputtered films agrees well with the properties of the bulk target material. However, the deviation of the magnetization below 200 mK implies a somewhat enhanced exchange interaction in the sputtered films compared to the bulk. Two possible causes of the increased interactions are (1) The indirect exchange (RKKY) is larger in sputtered films than in the bulk (2) Er ions are not randomly distributed in the sputtered films but are more likely to be found closer to other Er ions. Sputtered films produced from a lower concentration of Er and isotopically enriched in ^{166}Er are being pursued to learn how to produce high quality vapor-deposited MMCs.

Microfabrication of MMCs

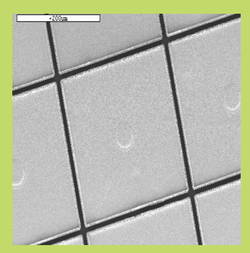
Photolithography + vapor-deposition technology can be used to fabricate arrays of MMCs

(Right) Au:Er sensor deposited in 50 um SQUID pickup loop





(Left) Array development for MMCs: sputtered sensor arrays



Thermal evaporation of Bi absorbers on top of sensor arrays deposited at GSFC (picture provided by Simon Bandler)

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